

# Spectroscopic and photometric surveys of the Milky Way and its stellar clusters in the Gaia era

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## Abstract

This contribution to the *Stellar Clusters & Associations: A RIA Workshop on Gaia* deals with surveys of stars, in particular spectroscopic surveys, with attention to their impact on cluster studies, and their connection with *Gaia*. I review some of the scientific reasons why we want large spectroscopic surveys, what requirements these put on the instrumentation. Then I turn to a review of the current and future instrumentation that will enable us to complement *Gaia*'s excellent distances and proper motions with the desired ground-based spectroscopy to obtain additional radial velocities and elemental abundances of high quality. This is a very fast moving area with several new surveys using existing and future multi-object spectrographs on 4- and 8-meter telescopes. As things change rapidly it is difficult to give adequate information on all these projects, but with the inclusion of links to the relevant web-sites the reader should be able to follow the latest developments as they unfold.

## 1 Surveying the Milky Way and its stellar components

In the past the Milky Way was surveyed to find our place in the Universe. Shapley (1918b,a) showed, using globular clusters, that the Sun's position in the Galaxy is not in any privileged central part but indeed quite far from the centre, towards the outer 1/3 of the stellar disk. Later studies focused on the oldest stars in order to figure out how old the Milky Way and its stars are. This enabled much work on the stellar populations in the Milky Way and provided constraints on theories of galaxy formation in general (e.g., Eggen et al. 1962). A good overview to our understanding of the Milky Way through large surveys and to the future prospects at the time is provided in the proceedings of the Joint Discussion 13 at the 26th IAU General Assembly (Corbally et al. 2006, in particular the contribution by Wyse (2006), see the footnote for where to access the articles)<sup>1</sup>.

Today, we survey our Galaxy to find out how the Milky Way fits in the general framework of galaxy formation and evolution provided by  $\Lambda$ CDM (e.g., Springel et al. 2008, 2005).

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<sup>1</sup>The table of content and all pdf-files are available at <http://sait.oat.ts.astro.it/MSAIt770406/index.html>

Or rather – we wish to use the Milky Way as a testbed for such models. The examples of this approach are many. Interesting examples include House et al. (2011), Sales et al. (2009), and Abadi et al. (2003). A striking example of the interplay between observations and theory is provided by the prediction that the number of, then, known dwarf spheroidal galaxies (dSph) around the Milky Way was at least an order of magnitude too low as compared with the then current predictions from the state-of-the-art  $\Lambda$ CDM modelling (Moore et al. 1999). At the time, about ten dSph galaxies were known (Mateo 1998). This led to much work studying if, for example, star formation could be inhibited in small dark matter halos, thus providing a solution such that they would never start shining with stellar light. The Sloan Digital Sky Survey (SDSS, Adelman-McCarthy et al. 2006) later provided a deep, multi-band, photometric survey of a significant portion of the sky. Vasily Belokurov and colleagues analysed this material and quickly found several more dSph, which were also confirmed spectroscopically, i.e., that the systems have a common radial velocity and are not just asterisms on the sky (Belokurov et al. 2007, 2009). A particularly difficult example is given by the Hercules dSph (Belokurov et al. 2007; Adén et al. 2009). An extrapolation from these, and subsequent investigations, points to the possibility that the Milky Way might actually be surrounded by almost as many dSph as predicted by  $\Lambda$ CDM. However, along the way many important lessons about galaxy formation and evolution have been learnt. Grebel (2011) provides a concise update on the theoretical as well as the observational studies tackling this problem.

Freeman & Bland-Hawthorn (2002) reviewed the prospects of identifying, with the help of *chemical tagging*, individual regions of star formation in the Galaxy. The chemical tagging concept builds on the understanding that all stars form in clusters and that each cluster should have a unique signature, not only in age but also in elemental abundances. The ability to identify unique groups of stars in this way is challenging, requires very large spectroscopic surveys, and has led to the proposal that underpins the HERMES project. We will return to the topic of chemical tagging and elemental abundances in Sects. 3 and 4.

## 2 Stellar clusters

Stellar clusters are an intrinsic part of any galaxy and provide vital clues to as diverse subjects as star-formation, stellar evolution, nucleosynthesis, understanding dynamical interactions between stars, and galactic formation and evolution. In many galaxies they are the most luminous individual objects that we can study also at very large distances. They can be used to constrain the formation histories of galaxies and put constraints on models of galaxy formation and evolution (Brodie & Strader 2006; Harris 1991). In the Milky Way, the two major classes of stellar clusters, open and globular, span a large range of ages and metallicities thus having the potential to play the role to constrain the formation and evolution of our Galaxy. The globular cluster population in the Milky Way contains only old clusters (Marín-Franch et al. 2009; De Angeli et al. 2005; Rosenberg et al. 1999). They divide into mainly two groups as concerns ages – the largest subset, containing only old clusters with very little spread in ages and a younger subset of clusters (a couple of billion years difference at the most) which are, based on their position within the Galaxy and chemical and kinematic properties, interpreted as being accreted from other systems, such as the Sagittarius dSph galaxy (Law & Majewski 2010). In other galaxies, e.g., the Large Magellanic Cloud, there are both old and young globulars (e.g., Colucci et al. 2011). The open cluster population in the

Milky Way mainly span younger ages, although there are open clusters as old as 10 Gyr (see Dias et al. 2002, with its associated data-base<sup>2</sup>). The globular clusters have a broad range of metallicities with two distinct peaks (something which is common to many galaxies, Harris et al. 2006), but they do not cover very metal-poor stars (below  $-2.2$  dex) nor stars with solar metallicities or higher (Zinn 1985; Harris 2010)<sup>3</sup>. The open clusters span metallicities higher than about  $-0.5$  dex (e.g., the compilation in Magrini et al. 2009, and the work by Friel et al. (2010)).

The different ranges in metallicities and ages for the two cluster populations is also reflected in (and connected with?) their spatial distributions. The globular clusters in the Milky Way mainly reside in a roughly spherical distribution. Kinman (1959) indicated that the globular cluster system in the Milky Way is composed of two kinematically distinct sub-groups with differing metallicities. The study by Zinn (1985) then later clearly showed that the more metal-rich globulars,  $[\text{Fe}/\text{H}] > -0.8$ , are centrally concentrated, whilst the less metal-rich globulars (in fact the majority of all the globulars in the Milky Way) form a much more extended, spherical system. These metal-poor globulars are thought to be associated with the stellar halo, although some of them are likely accreted from other, smaller, galaxies. Palomar 12 is one such example (Dinescu et al. 2000; Law & Majewski 2010). Forbes & Bridges (2010) discuss additional associations of globulars with dSph galaxies. For the metal-rich globulars sub-division into bulge and disk clusters have been discussed (see examples in, e.g., Minniti 1995; Zinn 1996; Harris 1998) but such divisions remain an open subject. For example, Bica et al. (2006) found that the metal-rich globulars have a spherical distribution, whilst Dinescu et al. (2003) found that at least one of them (NGC 6528) is, based on its kinematics, associated with the bar. This points to the necessity of getting more and better kinematic data also for globulars in order to understand the globular cluster system. In a series of important paper Dana Casetti-Dinescu and collaborators (Casetti-Dinescu et al. 2010, and references therein) have painstakingly derived the proper motions and space velocities for by now 34 globulars using the Southern Proper Motion Program data, steadily improving our understanding of the dynamics of the system. Very few globulars appear to be genuinely associated with the stellar disks. In fact most globular clusters are too metal-poor to be associated with the disks. The so far only, confirmed, disk globular is NGC 5927 for which the full 3D kinematic information shows it to have an essentially disk orbit (Casetti-Dinescu et al. 2007). The cluster has a metallicity,  $[\text{Fe}/\text{H}] = -0.37$ , as well as elemental abundances, e.g., Ca is enhanced relative to Fe, that naturally associate it with the thick disk (Simmerer et al., a study of 7 HB stars in the cluster, to be submitted).

Studies of elemental abundances in globular clusters is a large subject that was recently reviewed in detail by Gratton et al. (2004). The globulars do in general follow the abundance trends of the major stellar populations in the Milky Way, however, there is increasing evidence that there are aspects of “clusterness” that might set their stars apart from the stars normally observed in the field, e.g., they show Na-O anti-correlations which are not seen in the field stars (see, e.g., Carretta et al. 2009a,b; Marino et al. 2011) and more and more clusters are shown to have multiple stellar populations also based on their colour-magnitude diagrams

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<sup>2</sup>The data-base is available, together with links to many other open cluster catalogues, at <http://www.astro.iag.usp.br/~wilton/>

<sup>3</sup>Note that this is a new update on the *Catalog of Milky Way Globular Clusters* by W.E. Harris. The full data-base can be found at <http://physwww.mcmaster.ca/~harris/Databases.html>

(e.g., Piotto et al. 2007). The discovery of which has resulted in much theoretical work and deepening our understanding of star formation and evolution (see, e.g., D’Ercole et al. 2011). A good example of how an existing survey can be used to tackle a new problem is given by Lardo et al. (2011) who used publicly available photometry from SDSS to trace the two populations (UV-red and UV-blue) in globular clusters (cores excluded) and find that radial variations in the populations are present. This is feasible as the survey covers the cluster outskirts very well, till they dissolve into the field population, something that is not always feasible with dedicated programs.

Open clusters is a much larger subject than globular clusters. In particular since the clusters include young and heavy stars. Thus rare evolutionary stages can be studied in detail. The reader is directed to other contributions to this workshop for more details on the massive and young stars. Spectroscopic surveys will naturally have a large impact on the study of those rare evolutionary stages, however, I will limit myself to aspects of the open clusters that mainly concerns them as birthplaces of field stars, tracers of Galactic chemical evolution, structure, and dynamics.

In total we know of more than 1800 open clusters detected in the visual (Dias et al. 2002, and subsequent updates). For those about 50% have an age estimate (Moitinho 2010). In addition there are about 700 clusters detected in the near infra-red. For the about 200 open clusters with abundance estimates the most striking feature is probably the Galactic radial gradient in metallicity that they trace. Currently, very few other tracers are able to deliver well determined metallicities combined with good distance estimates (for the open clusters distances come from isochrone fitting). It appears that the disk as traced by the open clusters shows a steadily declining  $[\text{Fe}/\text{H}]$  as a function of galacto-centric distance, until it reaches a floor at about 10-12 kpc (Friel et al. 2010; Bragaglia 2010). Similar observations are not readily available for large data-sets in the field. A recent example of a small study of field giants shows, however, the same floor in metallicity (Bensby et al. 2011). In addition, the abundance trends found in the open cluster population appear to follow the abundances found in the thin disk very well, as shown in Friel et al. (2010) where they compare the  $[\text{O}/\text{Fe}]$  as a function of  $[\text{Fe}/\text{H}]$  with the data for kinematically selected thin and thick disk stars (Bensby et al. 2004).

Over the last few decades several studies and small and large surveys of both globular and open clusters in the Milky Way have been undertaken. In spite of all these efforts, there is still scope for very large and comprehensive surveys of stellar clusters. For example, only about 10% of the known  $\sim 1800$  open clusters have metallicity estimates available in the literature (Moitinho 2010). While about half of them have distances, ages, and reddening estimated. For the globular clusters the situation is somewhat more robust with 1/3 of the  $>150$  known globulars having metallicity estimates. Large area coverage not only in photometry but also in spectroscopy is clearly desirable.

### 3 Clusters and the underlying field populations

While the globular clusters appear to essentially trace the spheroidal components of the Milky Way, the Galactic bulge and halo, the open clusters reside in the disk. Essentially all open clusters have  $|b| < 20^\circ$  (see, e.g., Figure 1 in Moitinho 2010). Thus the globulars trace the

older parts, both the metal-poor halo and the metal-rich bulge, of the Milky Way, whilst the open clusters trace the, younger, stellar disk. The question then arise – Are these just “spatial coincidences” or do the cluster systems truly trace the underlying field population and can they tell us something about how those stellar components of the Milky Way formed and evolved?

It might first be interesting to consider if the populations of stellar clusters as we know them today are representative samplings of the underlying, full cluster populations. The answer to this is related to how we discover stellar clusters. For example, it is much easier to find a stellar system in parts of the sky that are less crowded and/or have low extinction. The stellar disk has, especially at the very lowest latitudes, a very large extinction, reaching many magnitudes towards the central parts of the Galaxy. How the presence of extinction influences our ability to find and study open clusters in the disk is illustrated in Fig. 2 in Moitinho (2010) which shows how the known open clusters nicely traces the low extinction areas in the first quadrant. Photometric searches in near infra-red surveys, such as 2MASS, have revealed many clusters hidden to surveys in the optical (e.g., Froebrich et al. 2007). The need for spectroscopic follow-up to confirm clusters against asterisms is further discussed in Bica & Bonatto (2011). The photometric near infra-red VVV survey (see page 8) has already discovered 96 new infra-red open clusters and stellar groups. These cluster candidates are mainly faint and compact and are younger than 5 Myr (Borissova et al. 2011). The high extinction of these new clusters, up to 20 mag in  $V$ , show how important it is to have near infra-red surveys to fully explore the cluster population that resides in the plane. In addition, for open clusters there is a clear tendency that more detailed studies have concentrated on the brighter or more well-populated clusters where the colour-magnitude diagrams are better populated (Moitinho 2010). In summary, we have only begun to scrape the surface of the properties of the open cluster system. Nevertheless, the open clusters, which clearly are currently forming within the stellar disk, are more likely directly related to the field population as such than the globulars are. It is worth pointing out that also globular clusters are found in the near infra-red surveys (e.g., Bonatto & Bica 2008). It will be interesting to see if the gap in, e.g., age and mass between the two sets of clusters will diminish or remain thanks to the new clusters found.

As discussed earlier, some globular clusters are likely accreted from other galaxies and are thus fossil records of other stellar populations than those in the Milky Way. It is in this context that good elemental abundances become interesting. We expect the abundance trends or patterns to be different for different systems (Tolstoy et al. 2009). This has, for example, been used in a wide range of studies of the Sagittarius dSph, its associated stellar clusters, and streams to pin down their common origin (e.g., Cohen 2004; Sbordone et al. 2005, 2007; Monaco et al. 2007; Mottini & Wallerstein 2008).

Stars form in cluster of varying sizes. Lighter clusters are anticipated to dissolve into the surrounding field on a short timescale. Olin Eggen was perhaps the first to investigate the so called moving groups (see, e.g., Eggen 1996, 1966). He identified a number of such groups based on their common space motions. Improvement in data, in particular the advent of the Hipparcos catalogue (Perryman & ESA 1997) which enabled the calculation of reliable space velocities, has re-ignited the interest in this field. A number of moving groups have been re-assessed and several new ones have been found (examples include Klement 2010; Bobylev et al. 2010; Famaey et al. 2007; Arifanto & Fuchs 2006; Barrado y Navascues 1998).

However, dynamical investigations indicate that some of the moving groups are kinematic features rather than dissolved stellar clusters (Dehnen 2000). If we assume that the stars were actually born together then they should not only have a common age but also share the abundance pattern. Thus spectroscopic abundance analysis to obtain elemental abundances is necessary to check if it is a cluster or a dynamical feature. De Silva et al. (2007) showed that HR 1614 is indeed a dissolved cluster with the stars sharing a common abundance pattern. The Hercules stream on the other hand was shown to just sample both thin as well as the thick disk abundances and ages, with a rather broad distribution in  $[\text{Fe}/\text{H}]$  proving its origin to be, most likely, the local dynamical effects of the bar (Bensby et al. 2007). The prospects of *Gaia* to improve our understanding of the stirring by the bar and spiral arms, and the connection to moving groups and dissolving stellar clusters in terms of Galactic evolution is further discussed in, e.g., Antoja et al. (2011) and Bovy (2010).

Also globular clusters loose stars which populate the field. Prominent streams have been detected, e.g., for Palomar 14 and 5 (Sollima et al. 2011; Odenkirchen et al. 2001, respectively).

## 4 Surveys to complement and enhance Gaia

*Gaia*<sup>4</sup> will observe a billion objects down to  $G \simeq 20$ <sup>5</sup>. *Gaia* will, apart from parallaxes and proper motions, provide photometric information for all objects enabling astrophysical classification (e.g., star or quasar) and astrophysical classification (e.g., effective temperatures, photometric redshift). For the 150 million stars brighter than  $G \simeq 16$  the on-board spectroscopic instrument will in addition provide radial velocities. For even brighter stars,  $G \simeq 12$  which corresponds to about 5 million stars, the spectrograph will in addition give interstellar reddening, atmospheric parameters, and rotational velocities. It will provide elemental abundances for the two billion brightest stars ( $G \simeq 11$ ). This leaves almost 90% of the stars observed by *Gaia* without radial velocity estimates and even more stars without any additional astrophysical information. Such information can be got from ground-based observations using efficient, multi-fibre spectrographs on 4- and 8-meter class telescopes.

That *Gaia* needs to be complemented with ground-based observations has long been recognized. For example the ESA-ESO Working group on galactic populations, chemistry and dynamics set out the challenges and priorities already in their report 2008 (Turon et al. 2008b,a), where they especially recognized the importance of powerfully multi-object spectrographs with high multiplex. ASTRONET's<sup>6</sup> consultations reach the same conclusions and their report concluded: "It is crucial to supplement the *Gaia* data-set with dedicated ground-based spectroscopic programmes, in order to obtain the radial velocity and detailed chemical abundances for fainter stars."

Depending on what scientific questions that are being asked the requirements on the

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<sup>4</sup>*Gaia*'s science performance is available at <http://www.rssd.esa.int/index.php?project=GAIA&page=Science.Performance>. The numbers on these web-pages are predicted to be robust until the mission flies, and no further updates will be given.

<sup>5</sup>*Gaia* magnitudes are in the white-light *G*-band which covers  $\sim 330 - 1050$  nm.

<sup>6</sup>ASTRONET was created by a group of European funding agencies in order to establish a long-term roadmap for European astronomy. The report *Science Vision for European astronomy* is available at <http://www.astronet-eu.org/-Science-Vision->.

derived abundances will differ. If for example we want to figure out which clusters belong to the Sagittarius dSph galaxy we may only need an internal precision of about 0.1-0.2 dex, while if we want to identify individual stars that belong to a dispersed stellar cluster we may need an internal precision in our measurements of about 0.05 dex or less. The latter can readily be refereed to as the chemical tagging suggested by Freeman & Bland-Hawthorn (2002) while the former is better refereed to as a chemical labelling, a term introduced by Vanessa Hill. It is important to make these distinctions because what you can learn from the various types of measurements differs significantly and has a straightforward, direct impact on the design of stellar spectroscopic surveys. Very high precision within a study is often reached by studying stars that in all respects are very similar in their stellar parameters and only differ in age and elemental abundances. Only selecting similar types of stars for the survey is a technique that has been successfully employed many times. Good examples include Edvardsson et al. (1993), Fuhrmann (2011), Bensby et al. (2004). Recently, the same methodology has been used to identify solar twins (Meléndez et al. 2010).

A summary of the necessary requirements on the equipment, based on actual science cases, was set out by a working group inside GREAT-ESF<sup>7</sup>. In the resulting document<sup>8</sup> we concluded that the best synergies with the on-board instrumentation on *Gaia* would be provided with the following three broad sets of instruments:

1. Low resolution spectroscopy for completion of the 6D phase space information for stars with  $16 < V < 20$ .
2.  $R = 20000$  spectroscopy of metal-poor disk and halo stars, giants as well as dwarfs, and stars in nearby dwarf galaxies. This mode will enable observations of stars at very large distances (4-m class telescopes).
3.  $R = 40000 - 60000$  multi-fibre and perhaps single slit spectroscopy of selected populations of metal-rich stars, e.g. disk and (outer) bulge (4- and 8-m class telescopes).

It is now very exciting times when some of these thoughts are put into practise through a number of efforts. Below some of the most relevant projects are being discussed.

#### 4.1 The Gaia-ESO Survey

The *Gaia-ESO Survey* is the result of the community's response to ESOs call for public spectroscopic surveys. The final proposal was for 3000 hours on FLAMES-UVES on VLT/UT2 to obtain radial velocities and elemental abundances for  $> 10^5$  stars and  $> 100$  stellar clusters covering all the major stellar components of the Milky Way. It has a fully stand-alone science case and will provide the first homogeneous overview of the distributions of kinematics and elemental abundances in the Milky Way. It is also designed to, later, take advantage of the *Gaia* astrometry.

The FLAMES-UVES spectrographs provides a unique opportunity to probe the Galactic components both locally in very high detail as well as on a larger scale with still very

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<sup>7</sup>GREAT-ESF is the Gaia Research for European Astronomy Training. Funding from ESF provides for meetings and visits. Its web-site is <http://www.ast.cam.ac.uk/iao/GREAT/> and its wiki is at <http://camd08.ast.cam.ac.uk/Greatwiki/GreatHome>

<sup>8</sup>The latest version, April 2010, is available here

good elemental abundances. The FLAMES spectra will enable the determination of individual elemental abundances in each star, yield precise radial velocities for a 4D kinematic phase-space, and map both kinematic gradients as well as abundance – phase-space structure throughout the Galaxy. The high-resolution fibres in the UVES spectrograph will be used to obtain high signal-to-noise spectra for a few thousand dwarf stars within 2 kpc providing a complete census of the distribution functions for the elemental abundances present in the old disk.

The *Gaia-ESO Survey* will be the first homogeneous spectroscopic survey of a statistically significant sample of stellar clusters. Encompassing clusters with ages from  $10^6$  up to  $10^9$  years, in different environments, with different richnesses and cluster masses, and different galacto-centric positions. For each cluster the survey will provide a “complete” stellar sample based on detailed chemistry as well precise kinematics. In addition it will also provide measures of stellar activity, quantitative mass-loss estimates for early-type stars, and refined memberships for cluster members.

An important aspect of this survey is the homogeneous abundance scale for stellar cluster and field stars. Thus enabling a truly differential study between the field the clusters are embedded in and the clusters themselves. Combined with the accurate velocity determinations for the stellar clusters this will lead to a deeper understanding of how the field is populated with stars from dispersing stellar clusters.

The *Gaia-ESO Survey* includes more than 300 astronomers across Europe and is Pled by Gerry Gilmore and Sofia Randich. The survey will have its own dedicated web-space at [www.gaia-eso.eu](http://www.gaia-eso.eu).

## 4.2 Selected instruments and their associated surveys

Currently, a number of multi-fibre spectrographs are either being commissioned, being built, or are undergoing studies. All of these are of direct relevance to the *Gaia* mission. In addition, many photometric surveys provide valuable data that will enhance the *Gaia* results. For instance, SkyMapper<sup>9</sup> has a filter system that is designed to be sensitive to stellar metallicity and gravity. This will complement the *Gaia* data with photometric metallicities for all stars too faint to get good metallicities from the on-board instruments. The SkyMapper filters roughly follow the Strömgren photometric system for which good metallicities can be derived for a range of stellar evolutionary stages (see, e.g., Adén et al. submitted, Casagrande et al. 2011; Adén et al. 2011; Árnadóttir et al. 2010). We may also foresee important complementarity to the *Gaia* from the photometric VISTA surveys, already operational and including the VISTA Variables in The Via Lactea (VVV)<sup>10</sup> multi-epoch public survey which will build a high resolution 3D map of the Galactic bulge including stellar variability (Minniti et al. 2010). The Galactic bulge is notoriously difficult to study thanks to the high and variable reddening. Thus the VVV will be a necessary complement to *Gaia*, which is not optimized for studies in such crowded regions with very high extinction. The variability studies will also add an interesting time dimension, enabling asteroseismology to be carried out on red giants. With such data also red giant branch stars can have their ages determined, something that

<sup>9</sup>More about the project, including the filter curves, can be found at <http://msowww.anu.edu.au/skymapper/>

<sup>10</sup>The survey wiki is available at [http://wmw.astro.puc.cl/mw/index.php/Main\\_Page](http://wmw.astro.puc.cl/mw/index.php/Main_Page)



is impossible without the very accurate masses provided by asteroseismology. Of the current surveys the Sloan Digital Sky Survey (SDSS) is probably that with the largest impact so far. The combination of its large photometric data-base and basic stellar parameters derived from low-resolution spectra (see, e.g., Lee et al. 2011, 2008) with the *Gaia* parallaxes and proper motions will very quickly result in new insights into the formation and evolution of the Milky Way. Other photometric surveys of interest includes Pan-STARSS<sup>11</sup> and Large Synoptic Survey Telescope (LSST Ivezic et al. 2008). LSST can be thought of as a deep extension *Gaia*. *Gaia*'s error in proper motion at  $r \sim 19$  is  $0.1 \text{ mas yr}^{-1}$ . This is LSST's smallest error and it performs to the same precision down to about  $r = 21$  (see further discussions on the synergy between *Gaia* and LSST in, e.g., Jurić & Ivezić 2011).

**RAVE** (the Radial Velocity Experiment) is an on-going spectroscopic survey obtaining radial velocities with an accuracy of about  $2 \text{ km s}^{-1}$  for up to a million stars. The spectra cover, as for *Gaia*, the Ca II triplet region. Elemental abundances for the RAVE stars have been derived from these as well as from follow-up spectra (e.g., Ruchti et al. 2010; Fulbright et al. 2010). Other recent, interesting results, showing the value of large, comprehensive spectroscopic data-sets, concern, e.g., the detection of young, moving groups (Kiss et al. 2011). Further examples can be found in the publication lists and news items on their webpage<sup>12</sup>.

**APOGEE** is part of SDSS-III<sup>13</sup>, which also includes the Baryon Oscillation Spectroscopic Survey (BOSS) as well as the MARVELS search for exo-planets, and the Sloan Extension for Galactic Understanding and Exploration 2 (SEGUE-2). The survey starts 2011. The spectrograph has 300 fibres, a wavelength coverage of  $1.52 - 1.69 \mu\text{m}$ , and a resolution of about 20 000. Over a period of four years it will obtain spectra ( $S/N=100$ ) for 100 000 red giant stars down to  $H = 13.5$  selected from 2MASS. From these spectra abundances for more than 15 elements will be derived as well as velocities with errors on the order of  $0.5 \text{ km s}^{-1}$ . The survey will observe around 200 stellar clusters, including 17 calibrating cluster. Of the calibrating clusters 12 are open clusters and 5 globular clusters (Frinchaboy et al. 2010). APOGEE is planning to work together with CoRoT and Kepler (KASC) to combine the good mass estimates for red giant branch stars provided by the space missions from asteroseismology with the detailed elemental abundances from APOGEE. The accuracy of the mass estimate is improved by the good abundance determinations. Combined, they will yield reliable ages for stars on the red giant branch. A task that otherwise is virtually impossible due to the very closely packed isochrones in this evolutionary phase.

**HERMES** is a multi-fibre spectrograph to operate on the the 3.9 meter Anglo-Australian telescope (AAT). The instrument will use the existing 2dF optical fibre positioner to place the 400 fibres over the two-degree field of view. The Galactic Archeology with HERMES (GALAH<sup>14</sup>) project starts in 2013. Observations are carried out in four wavelength ranges in

<sup>11</sup>More information as its surveys progress can be found at <http://pan-starrs.ifa.hawaii.edu/public/>

<sup>12</sup><http://www.rave-survey.aip.de/rave/>

<sup>13</sup><http://www.sdss3.org/> and <http://www.sdss3.org/surveys/apogee.php>

<sup>14</sup><http://www.aao.gov.au/HERMES/GALAH/Home.html>. A useful presentation is also available at <http://www.aao.gov.au/HERMES/ScienceWorkshop/Talks/gds.pdf>.

the visible covering 25 different species, including all the major nucleosynthetic channels. The resolution is relatively high at 30 000 with an option for even higher resolutions. The survey is limited to stars brighter than  $V=14$ . Even so, it will provide a very important first “all-sky” complement to *Gaia* delivering high quality elemental abundances for almost a million stars without elemental abundances directly measured using the *Gaia*-spectra. GALAH will use open and globular clusters for calibrating purposes as well as some very metal-poor stars to provide calibrations below the canonical  $-2.2$  dex, where the globulars stop.

**4MOST** is a proposed multi-object fibre spectrograph with a very high multi-plex to go on one of ESO’s 4-meter class telescope. The object is to provide *Gaia* and *eROSITA* with the necessary ground-based spectroscopy. The baseline is for a 1500 fibres with 3 degree<sup>2</sup> field-of-view with a goal of 3000 fibres over a 5 degree<sup>2</sup> field-of-view. The spectrograph has a low resolution mode for obtaining radial velocities and rough stellar parameters and a high resolution mode for chemical labelling. Examples of the Milky Way science that will be done with 4MOST include detailed studies of moving groups, dynamical structures as well as dissolving clusters, out to about 10 kpc. Hipparcos data allows us to study these features out to about 200 pc and does not allow for strong constraints on the bar and spiral arms (Antoja et al. 2011; Minchev et al. 2010). Its high-resolution survey will obtain chemo-dynamical data for more than  $10^6$  stars which allows, e.g., for studies of radial abundance gradient, i.e. the build up of the stellar disk, radial migration, formation of the thick disk etc. All open clusters will be thoroughly covered and the examples given above will allow for an even deeper understanding of the connection between the field and the clusters. A sub-survey aims at looking for truly large samples of the most metal-poor stars known. The instrument is undergoing a detailed phase A study and is PI:ed by Roelof de Jong (AIP)<sup>15</sup>.

**MOONS** is a proposed multi-fibre spectrograph operating in the near infra-red on the VLT employing 500 fibres over a field-of-view of 500 arcmin<sup>2</sup>. The science goals include *Gaia* follow-up and several extra-galactic science cases. From the point of view of Galactic Archeology and *Gaia* its major advantage over many other instruments is the combination of observations in the near infra-red with an 8-meter telescope. Thus it will provide a necessary complement to, e.g., *Gaia*’s radial velocities in the inner disk and Galactic bulge region. MOONS is also the ideal instrument to do spectroscopic follow-up and confirmation of cluster candidates found by photometric surveys in the near infra-red, as exemplified by the new results from the VVV survey (Borissova et al. 2011). The instrument is undergoing a detailed phase A study and is PI:ed by Michele Cirasuolo (Edinburgh).

**WEAVE** is a proposed multi-fibre spectrograph for the 4 meter William Herschel Telescope on La Palma. The design includes about 1000 fibres within a 2° field of view at the lower resolution of 5000 to, from the point of view of *Gaia* follow-up, provide radial velocities with an accuracy of less than 5 km s<sup>-1</sup> for stars with  $17 < V < 20$  and a high-resolution mode with  $R=20\,000$  for abundance determinations for stars (Balcells et al. 2010)<sup>16</sup>. The

<sup>15</sup>A presentation of the many science goals and the various design concepts was given at the GREAT-ESF meeting in Brussels 2011. It is available here.

<sup>16</sup>The project’s web-page is at <http://www.ing.iac.es/weave/>

instrument would, e.g., be ideal to characterize halo streams through chemical labelling, where a relatively low surface density maps well to the field of view and fibre density.

**Guoshoujing Telescope** (formerly LAMOST<sup>17</sup>) has a  $5^\circ$  field of view and 4000 optical fibres. It is currently working in a low resolution mode but updates to a higher resolution is foreseen. It covers the wavelength regions of 370-590 nm and 570-900 nm. The Guoshoujing Telescope telescope has its own, proposed, open cluster survey, LOCS (Chen et al. 2009), to, e.g., look at abundance gradients in the Galactic disk.

## 5 Concluding remarks

Although it is reasonably feasible to compare the major properties of a Milky Way galaxy formed in a  $\Lambda$ CDM simulation with the overall results from current photometric and spectroscopic surveys e.g., SDSS, SEGUE, RAVE) it is far from straightforward to constrain the models with the available data, mainly for two reasons: 1) the resolution in the models is too low to allow the investigation of the small scale features that we actually see in a real galaxies, 2) the selection of targets in the observational studies is either not well understood/documented or not optimized for the particular question of interest. Future surveys, especially the massive spectroscopic surveys operating after *Gaia* will be able to have very good selection criteria combined with, almost, exhaustive coverage of a given stellar population, hence enabling a more detailed comparison with models.

The several examples of past studies of the Milky Way and its stellar components given in this review show the need for large spectroscopic surveys to enable a full disentangling of the formation processes involved in shaping our Galaxy. Indeed, with the combination of *Gaia*'s distances and proper motion and a ground based massive follow-up providing the 6D phase-space as well as the multi-dimensional abundance and age space we will finally be able to start testing the models for real (compare, e.g., the proposed tests in Sales et al. 2009, which are only feasible with this new data). In addition, prepare to find the unexpected. This means, be ambitious also when it comes to the elemental abundances and aim for abundance errors smaller than 0.05 dex (internally) in order to find and tag also the small building blocks of our Galaxy, i.e. the open clusters.

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<sup>17</sup>Their official web-site is at <http://www.lamost.org/website/en>

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